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# The characterization of aliettite-bearing rocks of the Olympus mine, Stanleyville, Ontario

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**Abstract:** Aliettite, a rare, regularly interstratified talc-smectite clay mineral, occurs at the Olympus mine, Stanleyville, Ontario. The mine was originally developed for its vermiculite, which formed by hydrothermal alteration of metapyroxenite associated with local thrust faulting. The metapyroxenite generally consists of tremolite and diopside that have been replaced by talc, aliettite, and serpentine. Three stages of hydrothermal alteration are recorded, 1) replacement of tremolite and diopside by talc and phlogopite, 2) minor oxidation resulting in Fe-oxide-staining of talc, and 3) serpentinization of the phlogopite. The results suggest that aliettite formed by surface weathering superimposed upon earlier, low-temperature hydrothermal alteration.

**Résumé :** La mine Olympus, située à Stanleyville (Ontario), renferme de l'aliettite, minéral argileux rare composé d'interstratifications régulières de talc et de smectite. La mine a été mise en valeur à l'origine afin d'exploiter la vermiculite formée par l'altération hydrothermale de la métapyroxénite associée à la formation de failles de chevauchement à l'échelle locale. La métapyroxénite est généralement constituée de trémolite et de diopside qui ont été remplacés par du talc, de l'aliettite et de la serpentine. On a mis en évidence trois étapes d'altération hydrothermale, soit 1) le remplacement de la trémolite et du diopside par du talc et de la phlogopite, 2) l'oxydation peu importante entraînant la coloration du talc par l'oxyde de fer et 3) la serpentinisation de la phlogopite. Les résultats laissent supposer que l'aliettite s'est formée lors de processus d'altération superficielle superposés à une altération hydrothermale antérieure à faible température.

## INTRODUCTION

Mixed-layer clay minerals occur in a variety of geological environments and form by various processes including weathering and hydrothermal alteration. In Stanleyville, Ontario (Fig. 1), an occurrence of a rare, regularly interstratified, mixed-layer clay mineral, aliettite, has been reported (Percival et al., 1997). Aliettite, an interlayered talc-smectite (saponite variety) mineral, was originally discovered in ophiolite rocks in the Taro Valley, Italy (Alietti, 1958). Veniale and Van der Marel (1968) identified and characterized a similar mineral in serpentinite rocks of the Nure Valley, Africa, and named it "aliettite". It is typically found as a white clay that coats other minerals. At the Olympus mine property, aliettite is associated with altered Precambrian metapyroxenite and highly serpentinized rocks.

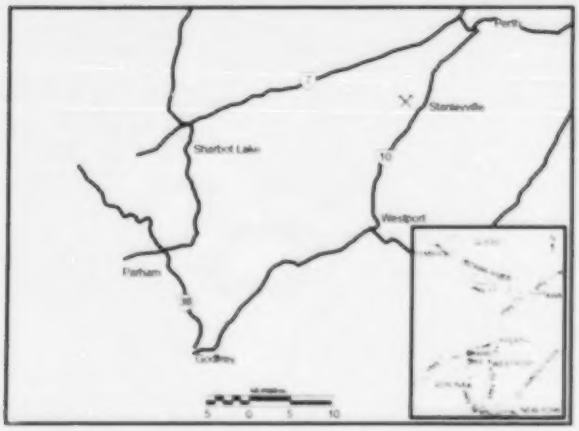


***Figure 1.*** *Location of Olympus mine in Stanleyville, Ontario.*

Because of the apparent global paucity of aliettite-bearing rocks, we thought it prudent to characterize the genetic and textural relationship of aliettite-bearing assemblages in the altered metapyroxenite of the Olympus mine. The current study is part of a larger project examining the genesis and occurrence of rare interstratified clay minerals at various sites in eastern Ontario using scanning and transmission electron microscopy (SEM-TEM; e.g. Percival et al., 1995).

## GEOLOGICAL SETTING

### *Regional geology*

The Olympus mine is located within the Frontenac terrane of the Central metasedimentary belt of the Grenville Province. It is cut by late Precambrian intrusive rocks and overlain by late Paleozoic rocks (Easton, 1992; Fig. 2). The emplacement of the Late Precambrian rocks was accompanied by regional metasomatism. In general, Grenville-series rocks include

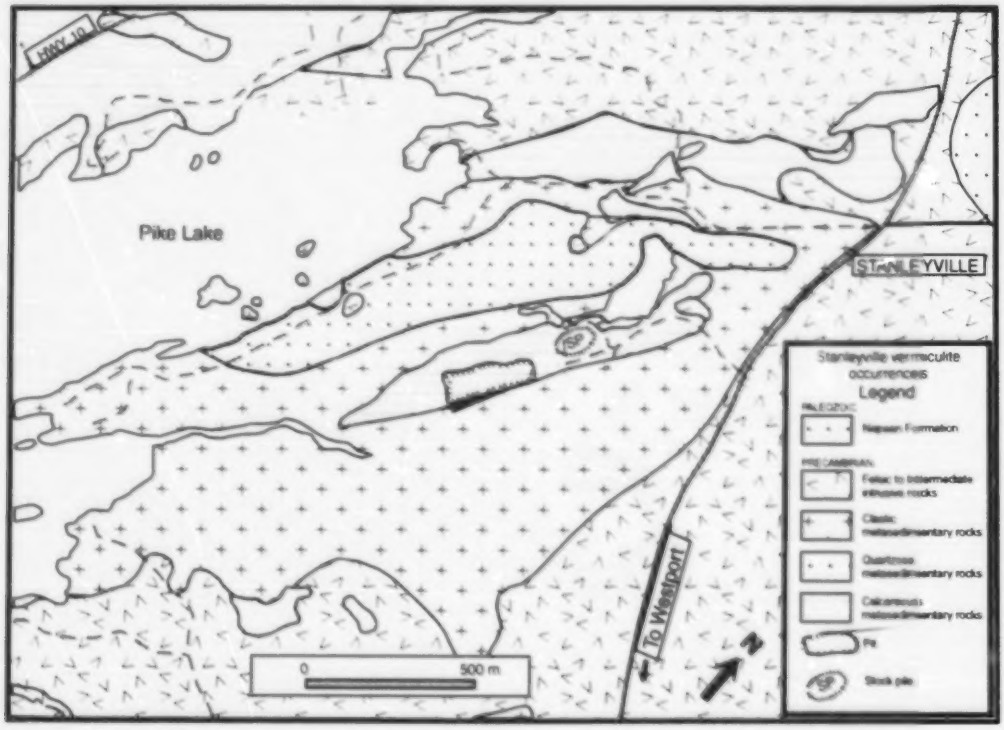


***Figure 2.*** *General geology of the Stanleyville area* (after *MacKinnon et al., 1990*).

paragneiss, quartzite, calcitic, dolomitic marble, and metapyroxenite (MacKinnon et al., 1990). The Central metasedimentary belt consists mostly of supracrustal rocks of the classical Grenville series, and is largely underlain by basement gneiss of the Central gneiss belt. The maximum age of rocks of the Frontenac terrane has been estimated at 1415 Ma (Easton, 1992).

### *Olympus mine site geology*

The study site is located on the northern half of lots 17 and 18, concession VIII, of North Burgess Township, Ontario, 0.8 km southwest of Stanleyville and 13 km southwest of Perth (Fig. 1). Vermiculite from the Olympus mine was used mainly in ultralightweight industrial aggregates and pet-waste absorbents. It was discovered by G.C. Bruce of the Ministry of Northern Development and Mines in 1950, and sold to Sisco Ltd. who trenched in 1959 and later sold to Olympus Mines Ltd. (MacKinnon et al., 1990). In 1960, Olympus Mines Ltd. developed the pit, which today lies dormant.

Vermiculite occurs in thin, pale green, serpentinized bands within highly friable metapyroxenite. The main mineralized zone strikes 52° and dips 80° NE, and has an average width of 40 m and a minimum length of 425 m (MacKinnon et al., 1990). It is associated with phlogopite and hydrobiotite, which occur in vertical veins observable on the northwest face of the open pit. The metapyroxenite in the hanging wall of the subordinate thrust fault is harder and less friable than that in the footwall rocks, indicating that the hanging-wall rocks were farther from the source of hydrothermal fluids (MacKinnon et al., 1990). Distal to the pit, the metapyroxenite is interbanded with the surrounding quartzite and actinolite-tremolite-talc schist.

## MATERIALS AND METHODS

### *Sample collection and preparation*

Samples of saprolite (99PNA 20 to 99 PNA 27) were collected from the east face of the open pit on August 5, 1999. Drill-core samples (DDH-01 to DDH-32) were also collected from the core library stored at the office of the Ministry of Northern Development and Mines in Tweed, Ontario, from drill-core box number TWO876. The list of samples and associations is given in Table 1. The samples were highly friable and creamy to greenish white. Samples (99 PNA 20, 99 PNA 21, 99 PNA 25, and DDH-09) were impregnated with epoxy to strengthen the rock for cutting and polishing. Polished thin sections of all samples were prepared by Vancouver Petrographics and six thin sections were selected for detailed analysis at subequal intervals throughout the drill core, including one sample from those collected at the surface.

**Table 1.** Sample number and depth from surface

| Drill core box no. | Sample no. | Depth (m) |
|---|---|---|
| N/A | 99 PNA 20 | at surface |
| N/A | 99 PNA 21 | at surface |
| N/A | 99 PNA 22 | at surface |
| N/A | 99 PNA 24 | at surface |
| N/A | 99 PNA 25 | at surface |
| N/A | 99 PNA 27 | at surface |
| B24.25 (0–6.1 m) | missing | 0–0.9 |
| | DDH-1 (1 cm thick) | 1.4 |
| | no core | 1.5–2.4 |
| | DDH-2 | 3.2 |
| | DDH-3 | 3.1 |
| | DDH-4 | 4.3 |
| B26-1 (6.1–12.2 m) | DDH-5 | 7.4–7.5 |
| | DDH-6 | 8.9–9.0 |
| | DDH-7 | 11.6–11.7 |
| B26-2 (12.2–18.3 m) | DDH-8 | 12.6–12.7 |
| | DDH-9 | 13.5–13.6 |
| | DDH-10 | 14.1–14.2 |
| B26-3 (18.3–24.4 m) | DDH-11 | 18.9–19.0 |
| | DDH-12 | 20.8–20.9 |
| | no core; too soft to core | 21.2–22.9 |
| | DDH-13 | 24.0–24.1 |
| B26-4 (24.4–30.5 m) | DDH-14 | 26.6–26.7 |
| B26-5 (30.5–36.6 m) | DDH-15 | 30.9–31.0 |
| | DDH-16 | 34.5–34.6 |
| B26-6 (36.6–42.7 m) | DDH-17 (massive sulphide) | 36.8–36.9 |
| | DDH-18 (talc) | 40.6–40.7 |
| B26-7 (42.7–48.8 m) | DDH-19 | 43.2–43.3 |
| | DDH-20 | 46.0–46.1 |
| | DDH-21 | 48.1–48.2 |
| B26-8 (48.8–54.9 m) | DDH-22 | 50.8–50.9 |
| | DDH-23 | 51.6–51.7 |
| | DDH-24 | 52.3–52.4 |

### *X-ray diffraction analysis*

The mineralogy of clay-sized (<2 μm) separates was determined by powder X-ray diffraction (XRD). Forty milligrams of sample were suspended in approximately 1 mL of distilled water, pipetted onto glass slides, and air-dried overnight to produce oriented mounts. X-ray patterns of the air-dried samples were recorded on a Philips PW1710 automated powder diffractometer equipped with a graphite monochromator using CoKα radiation. The samples were also X-rayed following saturation with ethylene glycol and heat treatment (550°C). Aliettite is recognized by a 24 Å (2.4 nm) air-dried peak that collapses to 9.49 Å (0.949 nm) upon heating.

### *Scanning electron microscope analysis*

All samples were examined using a Leica Cambridge Stereoscan S360 scanning electron microscope (SEM). The SEM was equipped with an Oxford/Link eXL-II energy-dispersion X-ray analyzer, Oxford/Link Pentafet Be window/light element detector, and an Oxford/Link Tetra backscattered electron detector. The SEM is operated at an accelerating voltage of 20kV. Images were captured at 768 by 576 by 256 greyscale and digitally stored for further processing.

### *Electron microprobe*

The six polished sections selected for detailed analysis were examined using a JEOL 733 microprobe, with Tracor-Northern 5500 automation and energy-dispersion spectrometer. Operating conditions were 15 kv, 20 nA, with a point-focus beam. Analyses were reduced with the SSQ analytical routine for semiquantitative standardless analysis.

## RESULTS

The dominant minerals observed in thin section include phlogopite, talc, amphibole (tremolite), pyroxene (diopside), pyrite, and serpentine. In most cases, the diopside and tremolite appear to have been replaced by talc, phlogopite, and serpentine, on the basis of corroded edges and the infilling of fractures along cleavage planes. Diopside and tremolite grains are much larger (0.1–1 cm) than the fine-grained talc and serpentine matrix (<1 mm average grain size). Tremolite, diopside, talc, and phlogopite are present throughout the entire section of the core. Pyrite is distributed locally through the samples and forms veinlets in phlogopite. Phlogopite occurs as large grains (approximately 1–2 cm) with rotational growth features that were also observable in hand samples (Fig. 3). Serpentine and talc are intimately related and intergrown with one another and with the phlogopite; the contact between them is indistinguishable. Vermiculite is found associated with a calcite-rich matrix and blebs of pyrite, or with phlogopite as intergrown crystals, but is not directly associated with talc. The degree of replacement of tremolite and diopside increases with depth throughout the core section.

The results from X-ray diffraction analyses are shown in Table 2. The samples representing the saprolitic zone on the northeast face of the open pit are dominated by talc, serpentine, and aliettite. Minor to trace amounts of phlogopite, amphibole, smectite (saponite variety), and corrensite (trioctahedral chlorite-vermiculite or chlorite-smectite) are also present. Aliettite was found in four of the six samples analyzed using X-ray diffraction. No pyroxene and only

**Table 2.** Qualitative clay mineralogical analyses by X-ray diffraction (A = abundant, m = minor, tr = trace).

| Sample number | Mineral identified |
|---|---|
| 99 PNA 20 | serpentine (A)<br>talc, phlogopite (A-m) |
| 99 PNA 21 | talc, amphibole (A)<br>serpentine (A-m)<br>**aliettite** (m)<br>geothite (tr) |
| 99 PNA 22 | smectite, talc (A)<br>phlogopite (A-m)<br>corrensite, **aliettite (tr)** |
| 99 PNA 24 | talc, smectite (A)<br>serpentine (m)<br>quartz (m-tr)<br>corrensite (tr) |
| 99 PNA 25 | smectite, talc (A)<br>phlogopite (A-m)<br>**aliettite** (m)<br>corrensite (tr) |
| 99 PNA 27 | serpentine (A)<br>**aliettite** (A-m)<br>smectite, talc (m)<br>K-feldspar (tr) |

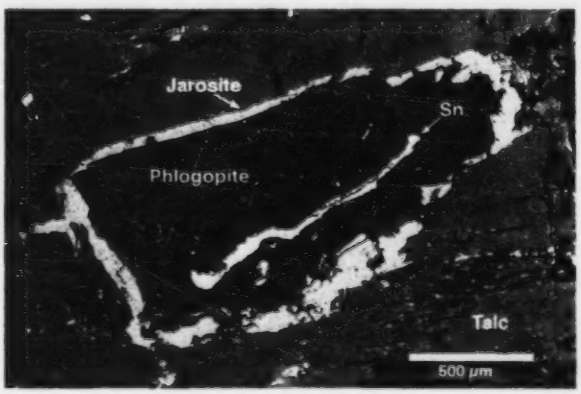


***Figure 3.*** *Scanning electron photomicrograph of a phlogopite grain rimmed by jarosite in sample 99 PNA 21 (backscattered image). Note the presence of tin (Sn) contamination from thin-section preparation.*

**Table 3.** Minerals identified by SEM and microprobe analyses.

| Sample number | SEM | Microprobe |
|---|---|---|
| DDH-01 | talc, phlogopite, iron oxide, diopside, apatite, tremolite | olivine, apatite, tremolite, iron silicate, phlogopite, vermiculite |
| DDH-08 | phlogopite, pyrite, titanite, talc, talc (with some Fe), carbonate | phlogopite, iron oxide, vermiculite, tremolite, talc |
| DDH-11 | **aliettite**, pyrite, phlogopite, talc, diopside | phlogopite, **aliettite** |
| DDH-19 | diopside, **aliettite**, quartz, phlogopite | phlogopite, vermiculite, **aliettite**, apatite |
| DDH-22 | phlogopite, diopside, talc | phlogopite, vermiculite, talc |
| 99 PNA 21A | Fe+Si, diopside, jarosite, phlogopite, talc, tremolite | vermiculite, iron silicate, phlogopite, tremolite |

accessory amounts of clinoamphibole were identified. Talc and serpentine were the most abundant minerals and dominated the mineralogy.

SEM analyses of polished thin sections selected for detailed analyses showed dominant tremolite, diopside, talc, and phlogopite (Table 3). Some grains of phlogopite in sample DDH-22 contained less potasium than others, and some grains in sample DDH-08 were enriched in iron. The SEM revealed small compositional variations in the amount of Mg and Fe in both phlogopite and talc. In sample 99PNA 21, a phlogopite grain is rimmed by jarosite forming an alteration halo (Fig. 3).

Aliettite and pyrite were found in minor amounts. A sample EDS spectra of a pure separate of aliettite is shown in Figure 4. Aliettite has additional Al and trace Fe in addition to a 1:1 ratio of Si to Mg in contrast to talc, which has a 2:1 Si to Mg ratio in EDS.

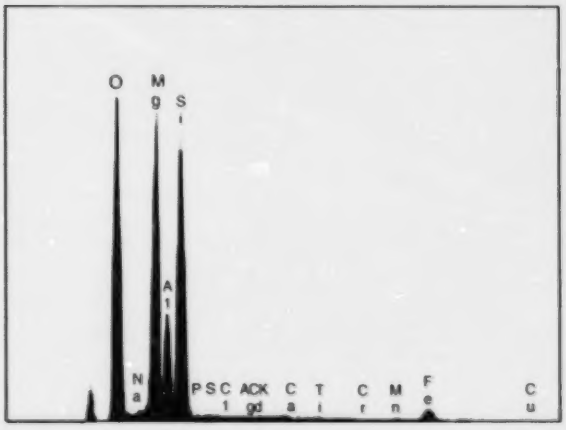


***Figure 4.*** *Example of EDS spectra of aliettite from a pure mineral separate showing a high ratio of Mg to Si and presence of Al.*

The minerals identified through microprobe analyses are also listed in Table 3. Phlogopite and tremolite were the dominant minerals identified whereas talc and vermiculite were less abundant. Probable aliettite was found in two samples, DDH-11 and DDH-19, which correspond to depths between 18.9 m and 43.3 m. Talc and aliettite do not occur together; talc occurs in samples taken above and below the aliettite. Tremolite and phlogopite are evenly distributed among all six samples analyzed.

## DISCUSSION

Studies of other vermiculite deposits such as that in Taro Valley, Italy, suggest that metamorphism and circulating meteoric water produce phlogopite followed by vermiculite during weathering processes (Alietti and Mejsner, 1980). The vermiculite stability field defines alteration temperatures below 300°C, otherwise chlorite would have formed (Luque and Rodas, 1986). Miles and Springer (1989) had initially reported that aliettite was found coating coarser, crumbly phlogopite and talc grains. In nearby marble, phlogopite found in crosscutting veins was completely replaced by corrensite (De Kimpe and Miles, 1988). Corrensite can form at the expense of phlogopite if there is a loss of interlayer $K^+$ combined with the formation of an expandable component and subsequent chloritization of alternate layers in the expanding mineral. De Kimpe and Miles (1988) indicated that the transformation of phlogopite, a relatively anhydrous mineral, to a more hydrated mineral such as corrensite, proceeds through the sequence phlogopite to vermiculite to smectite to corrensite. They concluded that corrensite formed during a late stage of hydrothermal activity and not associated with the main stage of metamorphism. A similar process for aliettite formation can be invoked given the association of corrensite at the Olympus mine.

MacKinnon et al. (1990) show phlogopite-diopside altering to vermiculite-talc at the Olympus mine. Aliettite was not observed to be in direct contact with vermiculite in the samples, but was observed replacing tremolite and diopside and

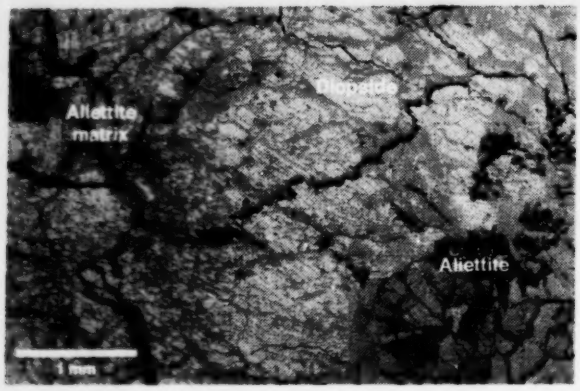


***Figure 5.*** *Scanning electron photomicrograph of aliettite replacing diopside (sample DDH 19; backscattered image).*

more commonly serpentine and talc (Fig. 5). The presence of smectite identified by X-ray diffraction and SEM analyses and the predominance of talc supply the components necessary to produce aliettite.

Three stages of hydrothermal alteration have affected these rocks. The first stage is represented by the replacement of diopside and tremolite by talc and phlogopite, which make up a large part of the matrix. The degree of alteration at this stage is so extensive that little of the original diopside and tremolite is left (Fig.5; MacKinnon et al., 1990). The infilling of cracks by pyrite to form veinlets suggests that the mechanism of alteration is hydrothermal in origin. Talc is stained with Fe-oxides defining a second phase of alteration, possibly due to hydrothermal or weathering processes. Serpentinized phlogopite represents the third stage of alteration. Aliettite was found to be most prominent in the saprolite zone on the east face of the open pit, and in samples DDH-11 and DDH-19. Generally, aliettite is more abundant at surface where the rocks are more weathered. Drill-core samples show less signs of weathering with depth.

The identifications reported here are consistent with the mineralogy reported by MacKinnon et al. (1990), i.e. tremolite, diopside, phlogopite, talc, and serpentine with accessory minerals such as corrensite, aliettite, and pyrite. Aliettite probably formed through surface-weathering processes superimposed upon earlier, low-temperature, hydrothermal-alteration assemblages.

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